New Window of Solar Physics: Solar Observations with ALMA

Masumi Shimojo[1],
Antonio Hales[2], Tsuyoshi Sawada[2], Richard Hills[3], Anthony Remijan[2], Stuartt Corder[2], Pavel Yagoubov[4], Masahiro Sugimoto[2], Shin'ichiro Asayama[1], Roman Brajsa[5], Tim Bastian[6] & Solar development study team of NA & EU

1: National Astronomical Observatory of Japan
2: Joint ALMA Observatory
3: University of Cambridge
4: European Southern Observatory
5: University of Zagreb
6: National Radio Astronomy Observatory


Shimojo

Abstract

The Atacama Large Millimeter/submillimeter Array (ALMA) is a radio interferometer for astronomy with extremely high performance that can also observe the Sun with less than 1 arcsec resolution. Because millimeter/submillimeter wave images probe high-energy electrons (>1 MeV) and chromospheric plasma, the data obtained with ALMA will give us new windows for flare physics and chromosphere studies. Solar observations with ALMA are in the commissioning phase. We carried out solar observing campaigns for commissioning and succeeded synthesizing solar images from the interferometric data obtained on 27 October 2013. To open solar observations of ALMA to heliophysics community, we are currently focusing our effort on data calibration methods. In the paper, we present selected preliminary results and discuss the current status of ALMA solar observations.

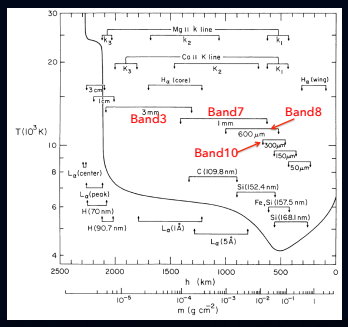
1: Introduction of ALMA & What does ALMA observe in the Sun?

- ALMA is a radio interferometer constructed from 54 12m-antennas and 12 7m-antennas. The maximum length of the baselines is 16 km.
- The observing frequency is 84 ~ 950 GHz (0.3 ~ 3.6 mm).
  - The 7 receivers (Band3,4,6,7,8,9 & 10) cover the frequencies.
- 4 (2) spectrum window (the bandwidth per a window: 2 GHz) in each Band (in Band9&10) can be observed simultaneously.
  - Each window can be divided into >128 channels.

[When a flare does not occur, …]

- Millimeter/submillimeter emission is thermal continuum from τ=1 layer.
  - It means that we see the radio photosphere!
- VAL model for QS shows that
  - The radio photosphere for ALMA is located in lower chromosphere.
  - The temperature ranges of ALMA observations is the same as that of Mg II k and Ca II K lines.

The details of the issue is shown in the poster #230 Wedemeyer et al.



Vernazza, Avrett, & Loeser (1981)

[When a flare occurs, …]

- The gyro-synchrotron emission with 86 GHz (Band3) needs electrons that energy is over 1 MeV.
  - The gyro-synchrotron emission with higher frequency needs higher energy electrons.
- The thermal emission from the high temperature and density plasma of a flare cannot be neglected.
  - We can divide it into thermal or non-thermal emissions from the spectrum.

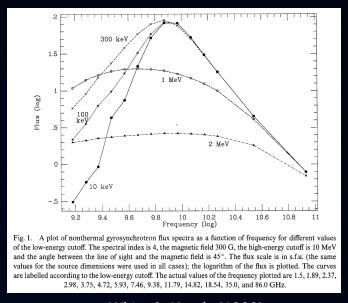


Fig. 1. A plot of nonthermal gyrosynchrotron flux spectra as a function of frequency for different values of the low-energy cutoff. The spectral index is 4, the magnetic field 300 G, the high-energy cutoff is 10 MeV and the angle between the line of sight and the magnetic field is 45°. The flux scale is in s.f.u. (the same values for the source dimensions were used in all cases); the logarithm of the flux is plotted. The curves are labelled according to the low-energy cutoff. The actual values of the frequency plotted are 1.5, 1.89, 2.37, 2.98, 3.75, 4.72, 5.93, 7.46, 9.38, 11.79, 14.82, 18.54, 35.0, and 86.0 GHz.

White & Kundu (1992)

2: History of Solar Observations with ALMA

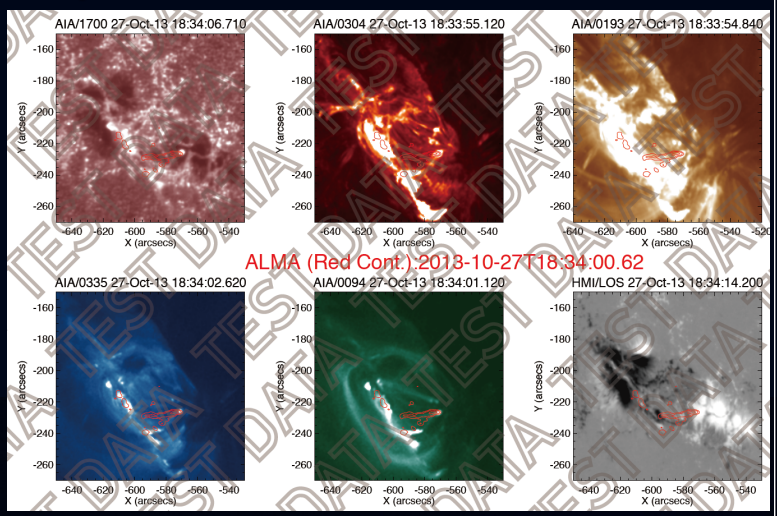
- Solar observations with ALMA are still in the commissioning phase.
- To open solar observations with ALMA to heliophysics community, we carried out four solar observing campaigns for commissioning as follows.
  - 1st Solar Campaign (June 2011)
    - ✓ Verified the tracking of solar structures using ephemeris files.
    - ✓ Obtained first firing of the Sun with ALMA.
    - ✓ Based on the results, we requested to change the attenuation level of the solar filters (-20 dB ➔ -10 dB).
  - 2nd Solar Campaign (December 2011)
    - ✓ Developed the script for observations with solar filters.
    - ✓ Established the method of measuring the delay caused by a solar filter.
  - 3rd Solar Campaign (June 2012)
    - ✓ First observation of the Sun using a 7m-antenna.
    - ✓ Verified the stability of the pointing and focus during a solar observation.
    - ✓ Verified the stability of the delay caused by the solar filters.
    - ✓ Established the simple observing sequence for solar interferometric observations with the solar filters.
  - 4th Solar Campaign (October 2013)
    - ✓ Succeeded in synthesizing the solar images from the visibility data obtained with the solar filters.

Note: All data in the campaigns are obtained with the Band 3 receiver.

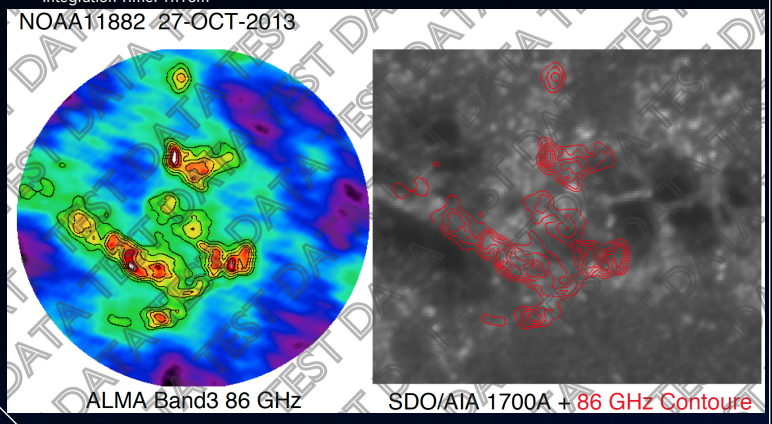
3: Preliminary Results of Previous Solar Campaigns

- Observation
  - Date: 27 October 2013 (4th Solar Campaign)
  - Target: NOAA11882
  - # of antennas: 12m 9, 7m 7 = Total 16
  - Receiver: Band3
    - Center frequency of each spectrum window: 86.3 GHz, 88.2 GHz, 97.3 GHz, 99.2 GHz
    - When we observed the Sun, the solar filters were inserted above the receivers.
  - All antennas connected to the BL Correlator with Time Domain Mode.
  - The size of the synthesized beam is 2 ~ 3 arcsec.
    - The shape of the beam is an ellipse.

- Preliminary Result 1: The 86.3 GHz image of a C1-class flare
  - Integration Time: 1 second



- Preliminary Result 2: The 86.3 GHz image of NOAA11882
  - Integration Time: 1h18m



4: Future Works for Opening to Community

We succeeded in synthesizing solar images from ALMA data obtained with the solar filters. However, the images have a critical weak point. It is that the flux calibration of the images might be impossible because we cannot use the calibration device located in the antenna when we use the solar filters. To resolve the problem, we are developing solar observations with the de-tuning SIS mixers. The method is that we reduce the sensitivity of the receiver by changing the bias voltage of the SIS mixer. Since such observing mode had not been considered during the developing phase of ALMA, we are checking the mode from the instrumental point of view now, carefully. 5th Solar Campaign is scheduled for this December. We will perform solar observations with the de-tuning SIS mixers in the campaign, and establish not only solar observations with ALMA but also the calibration method for synthesized solar images.

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